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DISPLAY MEASUREMENTS. THE EFFECTS OF HUD (HEAD-UP DISPLAYS) GLO--ETC(U)
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DISPLAY MEASUREMENTS --- The Effects of HUD (Head-Up Displays) Glow on Visual Performance

System Technology Branch
System Avionics Division

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February 1979
TECHNICAL REPORT AFAL-TR-79-1031
Final Report for Period 1 January 1977 - 30 September 1978

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFAL-TR-79-1031

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): DISPLAY MEASUREMENTS. (Head-Up Displays) The Effects of HUD Glow on Visual Performance.

5. TYPE OF REPORT & PERIOD COVERED: Technical Final Technical Rept. 1 Jan 77 — 30 Sep 78

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Richard A. Spearnock

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Avionics Laboratory (AFAL/AAT), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 2003 2006

11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Avionics Laboratory (AFAL/AAT), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433

12. REPORT DATE: Feb 1979

13. NUMBER OF PAGES: 17

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 17 pg.

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

DDC RECEIVED MAY 15 1979 C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Head-Up Display	Contrast
Glow	Contrast Ratio
Human Factors	Luminance
Displays	Adaptation Luminance
Surround	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report examines residual glow in head-up displays. The contrast threshold work of Blackwell is used to estimate the detrimental effects of this glow on operator (pilot) performance. It is shown that even small amounts of glow can have serious detrimental effects on performance. The amount of detriment is a function of the level of glow, the operator's state of luminance adaptation, and the perceived contrast ratio between the target and the surround. The methods used in this report can be used to examine cases other than the ones presented in the report as required.

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FOREWORD

This report is one of a collection of three technical reports written under Work Unit 20030628, "Liquid Crystal Display Measurements." The topics covered in these reports were chosen to either support this work unit directly or to help provide needed information for Work Unit 20030626, "The Integrated HUD." This work was accomplished during the period of 1 January 1977 to 30 September 1978.

The first report, "Measurement of Reflectance on Reflective-Type Displays," deals with the specification of reflectance in a two component sense. That is, reflectance is specified by both a diffuse component and a specular component. This formulation seems especially useful for specifying the reflectance of liquid crystal displays. However, the method is not limited to displays alone, but applies to any type of reflecting surface. For example, the reflectance of various aircraft coatings could be investigated using this method. The determination of the reflectance of these coatings is important and work has been done in this area, using methods other than the one of this report, by the Air Force Materials Laboratory. It is felt that specifying reflectance by this method may have advantages over other methods in current use. A simplified example using reflectance functions to calculate luminance and contrast ratio of an optical system which uses a liquid crystal display is included in the Appendix of the report.

The second report, "Can MTF Analysis Be Used On Matrix Displays?," investigates the use of modulation transfer function (MTF) in the evaluation of matrix displays. This report concludes that MTF analysis of matrix displays can be useful. An analytical estimate of the MTF of a hypothetical 1000 X 1000 element liquid crystal display is included in the report.

The third and final report of the series is titled "The Effects of HUD Glow On Visual Performance." This report deals with the effects of residual glow in head-up displays, and the effects of this glow on human visual performance. By using the contrast threshold work of Blackwell, it is shown that even small amounts of glow can have detrimental effects on operator performance. The amount of detriment is a function of the level of glow, the operator's state of luminance adaptation, and the perceived contrast ratio between target luminance and surround luminance.

The author thanks all those involved in helping him prepare these reports. I especially want to thank John Coonrod for his support and review of drafts.

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Introduction

This report examines the effects of head-up display (HUD) glow on visual performance. The results of the report are based on the work of Blackwell [1]. Blackwell's work in contrast thresholds was comprehensive and is an often cited reference in today's literature. Some work was done in the laboratory to get a feeling for the level of HUD glow tolerable and the glow ratio needed to reduce the glow to a level which would not affect operator performance. This is discussed further below.

This is not a comprehensive study into the effects of HUD glow for all levels of glow. However, by picking some reasonable cases, many questions have been answered concerning effects of HUD glow.

The Effects of HUD Glow

Glow is obtained in a HUD when the image source in the "off state" is not entirely dark, i.e., when no imagery is present on the image source, a residual luminance exists. This may be a problem in any HUD system regardless of image source type. This laboratory has addressed the problem, however, in regards to its work in developing a liquid crystal source for a HUD [2].

Glow in a HUD can cause two things to happen that affect operator performance. One is that the operator's state of luminance adaptation is altered. The other is that the contrast ratio between any target in the field of view and its surround is reduced as glow is increased from zero or no glow. Both of these effects are derivable from the equations to be presented below.

Laboratory Work

Work was done in the laboratory to find the maximum glow tolerable under a low light, night time condition. It was found that a level of 2.00×10^{-3} fl glow had a detrimental effect on both detecting and recognizing a target in a surround of approximately 0.8×10^{-3} fl. The values chosen in applying the Blackwell data were close to these laboratory values. Further it was found that the glow ratio (the ratio of the luminance of the symbology presented on the HUD to the luminance of the glow) was approximately 50 - 70 to 1 to not affect operator performance (at the particular luminance levels used, this ratio varies as target and surround luminance varies). Glow ratios of 50 to 1 and 35 to 1 were chosen to obtain results with the Blackwell data.

Pertinent Equations and Definitions

The following definitions and equations apply to the HUD glow analysis:

GR - glow ratio--luminance of symbology/luminance of glow

CR_g - contrast ratio with glow

CR_{ng} - contrast ratio no glow

α - % transmission of combiner

L_t - target luminance

L_g - glow luminance

L_b - background (surround) luminance

L_s - symbol luminance

L_a - adaptation luminance

Blackwell's definition of contrast ratio is as follows:

$$CR = \left| \frac{L'_a}{L_o} - 1 \right|$$

where L'_a is the luminance of the target to be detected and L_o is the background or surround luminance of the target.

For the HUD calculations, the target is assumed to have a luminance greater than the surround. With this assumption, the following equations apply.

$$CR_{ng} = \frac{\alpha L_t}{\alpha L_b} - 1 = \frac{L_t}{L_b} - 1. \qquad (1)$$

$$CR_g = \frac{\alpha L_t + L_g}{\alpha L_b + L_g} - 1 \qquad (2)$$

$$L_t = (CR_{ng} + 1)L_b \qquad (3)$$

$$L_a = \alpha L_b + L_g \qquad (4)$$

$$L_b = \frac{L_s}{GR} \qquad (5)$$

Equation (1) gives the no glow contrast ratio of target to surround as a function of combiner transmission, target luminance, and surround luminance. Note that the combiner transmission variable drops out. Equation (2) gives the contrast ratio with glow and is a function of the same variables as (1) with the addition of the glow luminance variable. Figure 4 shows the effect of glow on contrast ratio for various target luminances and a background luminance of 0.75×10^{-3} fl. Equation

(3) is derived from (1) and allows calculation of target luminance for a given no glow contrast ratio and background luminance. Equation (4) gives the adaptation luminance as a function of combiner transmission, surround luminance, and glow luminance. And finally, equation (5) gives the background luminance as a function of HUD symbol luminance and glow ratio.

Using the Blackwell Data

The following assumptions and calculations were made to use the Blackwell data. The cases examined were the 0.9 combiner, which was taken as the standard to compare all other cases, and a 0.7 combiner. The 0.9 combiner was examined for both a no glow and glow case. The glow cases were further broken down into 2 cases where the glow ratios were 35 or 50. Finally, two sets of cases were examined, one for an original no glow contrast ratio of 10 and a no glow contrast ratio of 1.

Calculations

A 0.1 fl symbol luminance was assumed. Therefore the glow was calculated as $L_g = \frac{L_s}{GR}$. For the GR = 50 case, $L_g = \frac{0.1}{50}$ = 0.002 fl, and for the GR = 35 case $L_g = \frac{0.1}{35} = 0.0029$ fl.

The background luminance L_b was assumed to be 0.75×10^{-3} fl. Using equation (4) $L_a = \alpha L_b + L_g$,

$$L_a = 0.9(0.75 \times 10^{-3}) + 0.002 = 2.68 \times 10^{-3} \text{ fl}$$

for the $\alpha = 0.9$, GR = 50 case. For the $\alpha = 0.9$, GR = 35 case,

$$L_a = 0.9(0.75 \times 10^{-3}) + 0.0029 = 3.58 \times 10^{-3} \text{ fl.}$$

Note for the no glow $\alpha = 0.9$ case,

$$L_a = 0.9L_b = 0.675 \times 10^{-3} \text{ fl,}$$

and for the $\alpha = 0.7$ no glow case,

$$L_a = 0.7\ L_b = 0.525 \times 10^{-3}\ \text{fl}.$$

Assuming $L_t > L_b$, the target luminance is calculated from equation (3) $L_t = L_b\ (CR_{ng} + 1)$. L_t is found to be 8.25×10^{-3} fl for $CR_{ng} = 10$. The target luminance $L_t = 1.5 \times 10^{-3}$ fl for $CR_{ng} = 1$.

The contrast ratio for the glow condition may be calculated from equation (2)

$$CR_g = \frac{\alpha L_t + L_g}{\alpha L_b + L_g} - 1.$$

The following table gives the CR_g values for the various combiner transmission, no glow contrast, and glow ratio cases.

Table 1

Contrast Ratio vs Glow and Glow Ratio
For $CR_{ng} = 10;1$

	Case	CR_g	$\log CR_g$
$CR_{ng} = 10$	α=.9 $L_t = 8.25 \times 10^{-3}$ fl GR=50 L_g=0.002 fl	2.52	0.40
	α=0.9 $L_t = 8.25 \times 10^{-3}$ fl GR=35 L_g = 0.0029 fl	1.89	0.28
$CR_{ng} = 1$	α=0.9 $L_t = 1.5 \times 10^{-3}$ fl GR=50 L_g = 0.002 fl	0.25	-0.60
	α=0.9 $L_t = 1.5 \times 10^{-3}$ fl GR=35 L_g = 0.0029 fl	0.19	-0.72

Using the Contrast Threshold Curves

Figure 11 from [1] is a graph which gives the log of visual angle in minutes of arc versus the log of threshold contrast for a time limited sighting of the target under various states of luminance adaptation. The horizontal scale has been changed as suggested in the Blackwell report to increase the probability of detection to something greater than 90%. The increase in target size for the various cases mentioned over the size required for th 0.9 combiner transmission case is a measure of the detrimental effect of both glow and reduced combiner efficiency on visual performance.

In Figure 1, the states of luminance adaptation (the curved lines) were first plotted for the $\alpha = 0.9$ and $\alpha = 0.7$ no glow case. Two vertical lines were drawn to plot the contrast ratio between target and surround. Again, contrast ratio is not a function of combiner transmission for the no glow case. The intersection of the $CR_{ng} = 10$ and $CR_{ng} = 1$ lines just plotted with the adaptation curves gives the target size required for threshold contrast. The results obtained from this graph indicate that the visual angle the target makes with the eye must be 12 to 17% larger with 0.7 combiner than the 0.9 combiner depending on CR_{ng}. Table 2 gives a summary of the results of all cases.

In Figure 2, the $CR_{ng} = 10$ glow case is examined. Using the same procedure as with Figure 1, the minimum visual angles are found for this case. Note that glow luminance changes with glow ratio thus changing contrast ratio CR_g and adaptation luminance L_a. The size of the target is read from this

Table 2

Summary of all Cases Studied.

The increase in visual angle required is indicated over that required for the α = 0.9 combiner case.

	Case	log ✱ subtense	✱ subtense (min of arc)	% larger
$CR_{ng} = 10$	0.7 combiner	0.79	6.17	12%
	0.9 combiner	0.74	5.50	standard
	0.9 combiner GR = 35	0.94	8.71	58%
	0.9 combiner GR = 50	0.92	8.31	51%
$CR_{ng} = 1$	0.7 combiner	1.40	25.12	17%
	0.9 combiner	1.33	21.38	standard
	0.9 combiner GR = 35	1.63	42.66	100%
	0.9 combiner GR = 50	1.58	38.02	78%

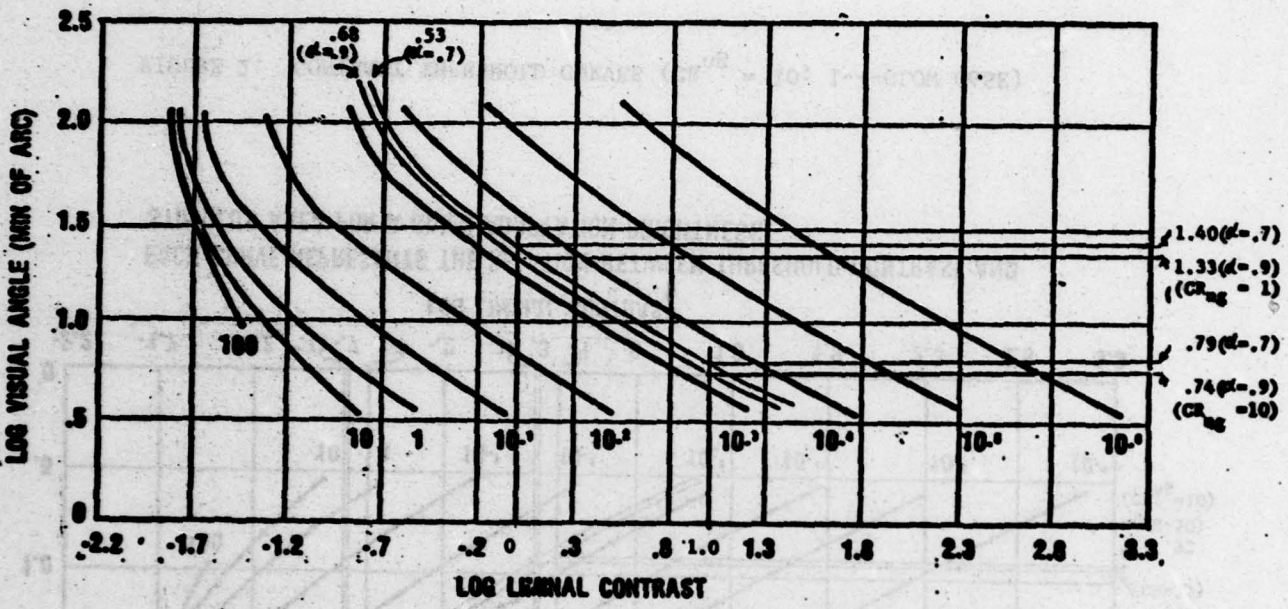
graph and is found to be 51% larger than the $\alpha = 0.9$ no glow combiner case with GR = 50 and 58% larger with the GR = 35. The combiner efficiency α was equal to 0.9 for both glow ratios.

Also in Figure 2, the $CR_{ng} = 1$ glow case is examined. The results are obtained using the same method as before. For the $\alpha = 0.9$ and GR = 35 case, the visual angle of the target must be 100% larger than the $\alpha = 0.9$ no glow standard. For the $\alpha = 0.9$ and GR = 50 case, it was found that the angular subtense of the target must be 78% larger.

Conclusions

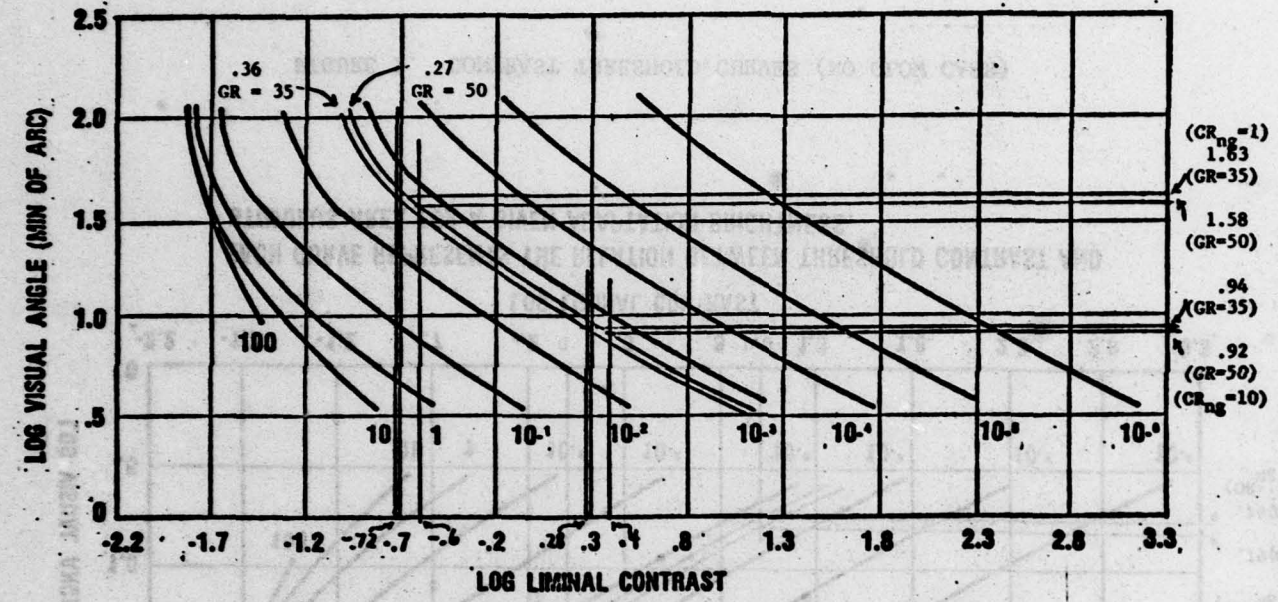
It appears that even small amounts of glow have serious detrimental effects on operator performance under low light level adaptation. This has serious implications on whether or not head-up displays which have glow should be used as primary flight instruments at night. It is believed, however, that if the HUD is only to be used with sensors that help the pilot see that which could not be seen with the unaided eye, the effects may be tolerable. This really represents another case than the one studied.

The effects of HUD glow on operator performance should be studied further if the intent is to someday use the HUD as a primary flight instrument at night.



EACH CURVE REPRESENTS THE RELATION BETWEEN THRESHOLD CONTRAST AND STIMULUS AREA FOR A GIVEN ADAPTATION BRIGHTNESS.

FIGURE 1. CONTRAST THRESHOLD CURVES (NO GLOW CASE)



EACH CURVE REPRESENTS THE RELATION BETWEEN THRESHOLD CONTRAST AND STIMULUS AREA FOR A GIVEN ADAPTATION BRIGHTNESS.

FIGURE 2. CONTRAST THRESHOLD CURVES (CR_{ng} = 10; 1---GLOW CASE)

References

1. Blackwell, H. Richard "Contrast Thresholds of the Human Eye," Journal of the Optical Society of America, Vol 36, No 11, pg 625, November 1946

2. Coonrod, J.F. and M.N. Ernstoff, "Advanced Head-Up Technology - The Integrated HUD," NAECON 77 Proceedings, pg 981